be less than three right angles, but in this case the total volume of space would still be infinite. Now, this is an hypothesis to be tested by experience. Unfortunately, we cannot triangulate from star to star; our limits are the two extremes of the earth's orbit. All we can say is that, within those narrow limits, the measures of stellar parallax give no indication that the sum of the angles of a triangle in stellar space differs from two right angles. If our space is elliptical, then, for every point in it—the position of our sun, for example—there would be, in every direction, an opposite or polar point whose locus is a surface at the greatest possible distance from us. A star in this point would seem to have no parallax. Measures of stellar parallax, photometric determinations and other considerations show conclusively that if there is any such surface it lies far beyond the bounds of our stellar system.

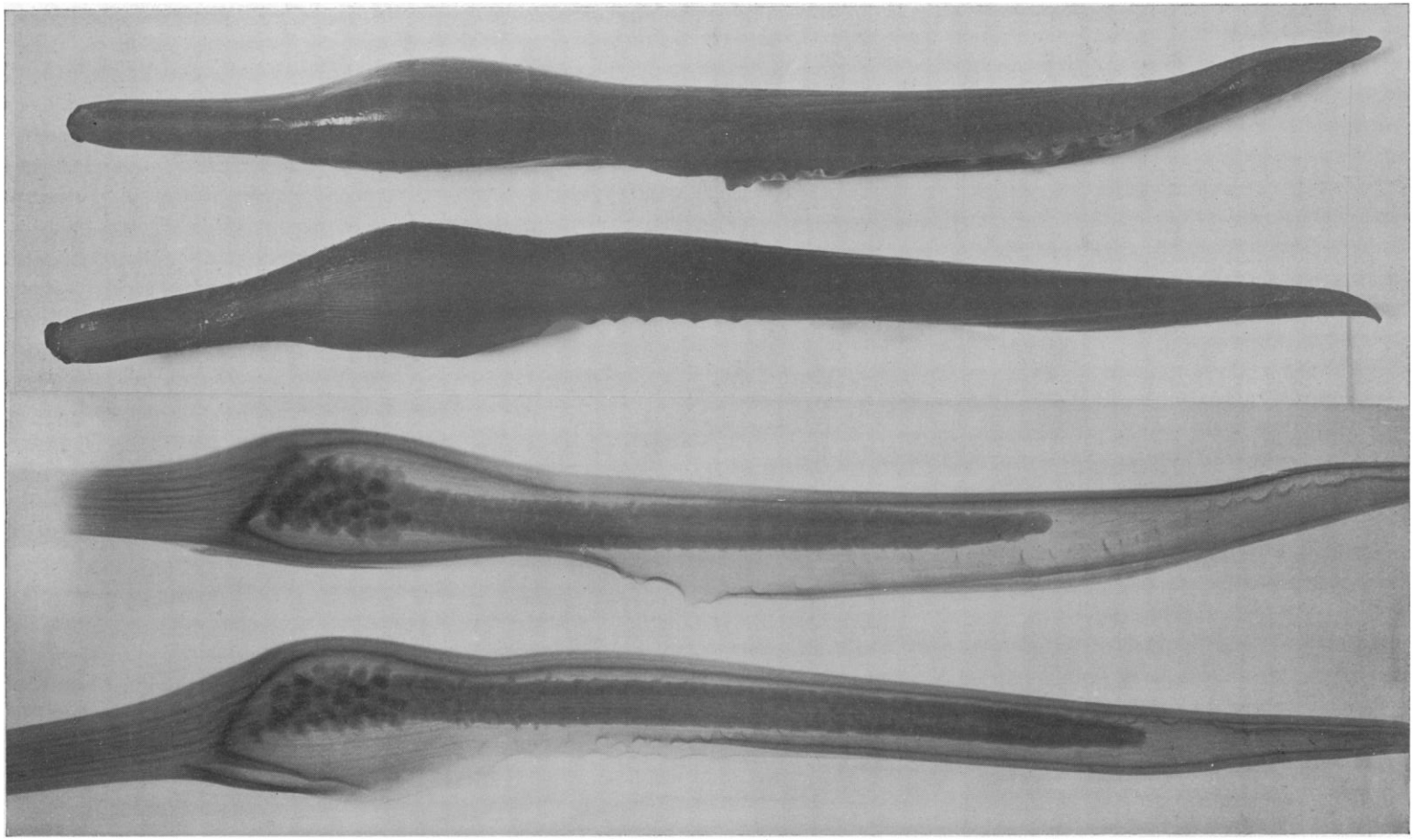
Such are the considerations by which it seems to me that speculations on this subject may legitimately be guided. The wise man is one who admits an infinity of possibilities outside the range of his experience, but who in considering actualities is not decoyed by the temptation to strain the facts of experience in order to make them accord with glittering possibilities. The experience of the race and all the refinements of modern science may be regarded as showing quite conclusively that, within the limits of our experience, there is no motion of material masses in the direction of a fourth dimension, no physical agency which we can assume to have its origin in regions to which matter cannot move, when it has three degrees of freedom. Claiming this, we must carry the claim only to the limits justified by actual experience. We have no experience of the motion of molecules; therefore we have no right to say that those motions are necessarily confined to three dimensions. Perhaps the phenomena of radiation and electricity may yet be explained by vibration in a fourth dimension. We are justified by experience in saying that the space relations which we gather from observation around us are valid for the greatest distances which separate us from the most distant stars. We have no right to extend the conclusion further than this. We must leave it to our posterity to determine whether, in either way, the hypothesis of hyper-space can be used as an explanation of observed phenomena.

S. NEWCOMB.

REPORT UPON SOME PRELIMINARY EXPERIMENTS WITH THE RÖNTGEN RAYS ON PLANTS.

SINCE it is a matter of some interest to know what influence, if any, the Röntgen rays would exercise on plants, I undertook a series of somewhat extensive preliminary experiments, to determine what lines of investigation might profitably be carried on should there be marked indications of any response to possible stimuli from this source.

The lecture room of our botanical department being connected by separate electric wire for the stereopticon, and the wire passing within a few metres of the end of one of the houses of the (*botanical*) conservatory, the current could be connected with the apparatus in the glass house with little trouble and expense. The connecting of the electric wires with the house was done under the direction of Professor H. J. Ryan, of the Sibley College of Mechanic Arts. An ordinary tin frame rheostat and an App's Coil were loaned by Professor E. L. Nichols, of the physical department, and the Crookes tubes used were of a pattern recommended by Professor Nichols, who, at the beginning of the experiment, set up the apparatus. To him I am indebted also for advice concerning the use of the apparatus, and also to Professor E. Merritt, of the physical department.



Illustrating Article by Professor G. F. Atkinson on 'Report of Some Preliminary Experiments with the Röntgen Rays on Plants.' *Peltandra undulata*: normal photograph above, Röntgen photograph below.

The portion of the conservatory employed for the experiments was the north end of one of the houses, where a bench space of about 2m. x 3m., and the height of the house, was enclosed as a dark room, by hanging black canton flannel and covering this on the outside and on the roof of the house with coarse cloths or board frames to exclude the light.

Experiment 1. Since in a number of cases the use of the Röntgen ray for exploring internal parts of the human body has resulted in certain injuries which are supposed to be due to some action of the ray, the first of the series of experiments which I conducted with plants was for the purpose of ascertaining if there was any marked injury which could be induced by an exposure of about one hour's time. Indeed, those with whom I discussed the matter prior to the investigations, and who were familiar with the use of the rays for other purposes, were inclined to think that distinct injuries would be produced. For the first experiment a potted Caladium about 60 cm. high was used. One leaf was supported directly in front of the bulb and about 10 cm. distant, while a flat metal key was suspended over the center of the leaf to intercept the rays at this point. The light was turned on at 11:07 a. m., June 6th, and a continuous run was made of 1 hr. 18 mins., *i. e.*, until 12:25 p. m. There was no visible effect at the close of the exposure and subsequently the leaf remained to all appearances normal.

Experiment 2. For the next experiment seedlings of corn, oats, German millet, sunflower and radish, which had been germinated in small 2-inch pots a few days before were used. The seedlings varied from 5 to 10 cm. in height. The pots were placed directly in front of the bulb, in such a manner that each kind of seedling was situated at different distances from the bulb in a radiating row. The experiment started at 1 p. m., June 6th. A piece of black canton flannel was tied over the bulb to intercept the electric light rays, so that their influence would not be felt, and this was kept over the bulb during all the subsequent experiments. At 2:45 p. m. it was noticed that the plants nearest the bulb were so close that electrical discharges took place between the bulb and the leaves, causing the plants to nod constantly toward the bulb and even to come sometimes in contact with it as the spark was formed. They were then moved to a distance of 15–20 cm. At nearly 4 p. m. all the plants were removed for a period of about three minutes while exposures were being made to obtain photographs. With this exception the seedlings were exposed to the influence of the Röntgen ray for a period of ten hours, the run being made from 1 p. m. to 11 p. m., when the dynamos were shut down for the night. No injurious effect was noticeable nor could any be detected later.

Experiment 3. The next experiment was started at 6 p. m., on June 6th. For this were used seedlings of corn, wheat, sunflower, radish, German millet and soja bean. The seedlings were grown in a dark room and were, therefore, etiolated, and varied from 8 cm. to 20 cm. in height. The plants were exposed that evening continuously for five hours. The wheat, German millet and corn seedlings were so frail that they drooped in various directions. At 9 p. m. it was noticed that the seedlings of the soja bean were turned slightly toward the bulb, while at the beginning of the experiment they were turned away from it. No perceptible injury took place.

Experiment 4. A potted begonia plant was placed so that the delicate flowers hung in front of the bulb within 10 cm. and remained there for five hours. There was no perceptible injury at the close of the run; nor on any subsequent days could injurious effects be observed.

Experiment 5. A potted plant of Caladium was placed with the leaf within 20 cm., with a small piece of sheet lead so placed between it and the bulb as to intercept a portion of the rays. The exposure continued for five hours. At the close of the experiment, and subsequently, no change could be observed.

Experiment 6. On June 8th a large number of seedlings which had been started previously in soil contained in wooden trays were placed in front of the light and exposed for several days. The seedlings used were those of corn, oats, wheat, radish, sunflower, soja bean, white lupine, cucumber, vetch, pea, German millet and cotton. There were several duplicate sets of the seedlings for this experiment; one lot was planted June 1st and the other June 5th, to provide seedlings in different stages of growth. From some which were just germinating they ranged in size to those which were 10 cm. high. The following gives the facts concerning the condition of the seedlings on June 8th, at the time of starting the experiment:

LOT 1. PLANTED JUNE 1ST.

NAME OF PLANT.	CONDITION JUNE 8TH.
Sunflower	5—8 cm.
Wheat	8—10 cm.
German millet	3 cm.
Nonpareil bean	just coming through the soil.
Soja bean	5 cm.
Cotton	just coming through the soil.
Oats	8—10 cm.
Corn	5—8 cm.
Vetch	5—8 "
Pea	2—5 "
Cucumber	2—4 "

LOT 2. PLANTED JUNE 5TH.

NAME OF PLANT.	CONDITION JUNE 5TH.
Cotton	germinating.
Wheat	germinated.
Sunflower	nearly up.
German millet	germinated.

The boxes containing the seedlings were so arranged that some of the seedlings were very near the bulb, while others were at varying distances, to the front, and right and left, so that if any distinct influence was manifested the extent of the field of this influence could be easily determined, and its degree, to some extent, be measured by the effect on the plants at varying distances. The field was explored with a fluoroscope to be certain that the rays reached all the plants which were placed in front of a line a few centimetres in advance of the bulb. A check lot of the seedlings was placed behind the instrument in the dark room in which the experiments were being conducted, so that they might grow under exactly the same conditions, except that they would not be under the influence of the Röntgen rays.

The experiment was started at 11 a. m., June 8th. The run was continued until 11 p. m., but since the interrupter in connection with the coil did not work satisfactorily the circuit was permanently broken at intervals. During this period the current was on about one-half the time. The following day, June 9th, the interrupter continued to work unsatisfactorily, and finally broke down at 5 p. m., the current having been turned on at 8 a. m. During the day of June 9th the instrument was running about one-fourth of the time. The interrupter was repaired and the current was started again at 10:20 a. m., the following morning, June 10th, and a continuous run was made up to 11 p. m., June 11th, the run was continuous from 8 a. m. until 11 p. m., and on June 12th, Saturday, from 8 a. m. to 4:30 p. m., when this experiment was discontinued.

During all of this time the plants behaved exactly as one would expect them to in an ordinary dark room. Those which had not come above the soil before they were placed under the influence of the Röntgen rays were entirely etiolated, while the new growth of shoots and leaves on

those which had attained some growth before the beginning of the experiment was also etiolated, the shoots being slender and the leaves small. The leaves, which were green at the start, gradually became nearly or quite yellow. The wheat, oat and millet seedlings were so weak that they fell prostrate, lying in all directions. At times it appeared as if the rays might have some peculiar taxic influence, since some of the seedlings were turned, now in one direction and at a later time in another, but there was no constancy in any of these movements, and they were ascribed to nutation. In fact, seedling plants which were in the path of the Röntgen rays for a period of over forty-five hours during five days did not at the close of the experiment appear in the least different from those in the same dark room, but which were out of the reach of the rays, and there was no appreciable difference in behavior during the continuance of the experiment.

That the seedlings were susceptible to directive influences of ordinary daylight was shown by their behavior when the dark compartment was opened. At one time the compartment was opened by parting two of the hanging dark curtains for about two minutes. Two hours afterward, when the compartment was again opened, nearly all the plants were turned strongly toward this point. This appears to me to be an interesting illustration of the great sensitiveness of these etiolated plants to light, and proves the fact that the response to the stimulus occurs some time subsequent to the stimulus.

The plants used in this experiment were now placed in normal light, and were observed carefully for several days. All of the etiolated plants gradually became green, but it was noticeable that those which were not under the influence of the Röntgen rays recovered more rapidly, though the difference was not very striking. This suggests that there may be some subtle injurious influence on the chloroplastids of the plant.

Experiment 7. The next experiment was started on June 14th, at 9 a. m. The dark cloth had been removed for the purpose of growing seedlings under the Röntgen rays which were at the same time exposed to normal daylight. The seedlings were arranged in front of the bulb in the same way as described for experiment 6. The following seedlings were used: squash, wheat, oats, pea, vetch, cow pea (*Dolichos*), sunflower, radish, soja bean, nonpareil bean and cotton. The seeds were planted a few days in advance, so that they were just coming through the ground in various stages when the experiment was started. A run of fourteen hours was made on June 14th, and of nine hours on June 15th, when this experiment terminated. No influence whatever from the Röntgen rays was observed.

In 1896 Schober* published the results of some experiments with the Röntgen rays on seedlings; these were undertaken for the purpose of determining if short exposures to the rays would produce taxic movements in the nature of curving or bending of the seedlings. Young oat seedlings were used which had been germinated in a dark room, and they were enclosed in a small geotropic chest, blackened both on the inner and outer side. This was so placed that they were at a distance of two cm. from the bulb at the opening of the chest. They were exposed for one half hour, and after a short interruption for another half hour. No turning had taken place. In order to see if the seedlings were sensitive to the light they were then placed near a small opening in the side of the room, and in the course of an hour perceptible heliotropic movements began, which were more marked

*Schober, A. Ein Versuch mit Röntgen'schen Strahlen auf Keimpflanzen. Ber. d. deutsch. Bot. Gesell. XIV., 108–110, 1896.

at the close of two hours, when they stood at an angle of 60°. He concludes from his experiments that the Röntgen rays have no taxic influence on seedlings.

Experiment 8. Three species of Mucor were sown in dilution cultures in nutrient agar-agar, in Petrie dishes. After the spores had begun to germinate one culture of each was placed within 25 cm. of the bulb, and the rays were then intercepted from one-half of each culture by a piece of sheet lead. A duplicate set of the cultures was placed out of reach of the rays. The cultures were exposed for four hours, and returned to the culture room. No difference in growth was perceptible, the Röntgen rays neither inhibiting nor hastening growth.

Experiment 9. Several forms of chromogenic bacteria were then subject to the influence of the rays. Several tube cultures in nutrient agar-agar were placed within 10 cm. of the bulb for about four hours. A duplicate set was kept in the same house, but outside of the field covered by the Röntgen rays. From each of the two sets of cultures inoculations were made into fresh nutrient media. There was no perceptible difference in growth nor in the color as a result of the exposure to the rays.

Experiment 10. A motile bacillus, *B. communis*, was next placed within 15 cm. of the bulb. The cultures were made in bouillon and poured into Petrie dishes. Two Petrie dish cultures were employed, and the rays were intercepted from one-half of each by sheet lead. They were exposed six hours. From each half of the two cultures then one drop was carried to the third dilution, and four cultures were then made from each of the second and third dilutions in nutrient agar, and distributed in Petrie dishes in order to compare the number of colonies. The results showed no difference in the proportionate number of bacilli in the two halves of the Petrie dishes. The rays, therefore, have no influence on the distribution of the bacilli in the liquid, nor on their vitality for the length of time exposed, a fact which Professor Marshall-Ward had already demonstrated.

Experiment 11. A species of motile Oscillatoria was distributed in six watch glasses with a small amount of water, the threads being arranged in a tangled mass in the center. Two of these were placed within 8 cm. of the bulb, two others at a distance of 20 cm. with the Röntgen rays intercepted by sheet lead, and the other two placed outside of the dark room. The experiment began at 12:30 p. m. and was discontinued at 4:30 p. m. In all the vessels during this period of four hours the threads moved out in a radiating fashion from the center, and some had moved partly up the sides of the vessels. In one of those exposed to the influence of the rays the thread had moved farther than in any of the others, while in the other five vessels no difference in the extent of the movement was observed, and the greater movement of the threads in one of the two exposed to the rays could probably be accounted for on other grounds.

Experiment 12. The influence of the rays was next tested on sensitive plants, *Mimosa pudica*, grown in pots. Two plants were used, and both were jarred, so that the leaves dropped on their petioles and the leaflets closed in pairs. The larger one, *a*, was placed so that the nearest leaves were within 10 cm. of the bulb after the dark room had been dispensed with. The smaller one was placed in another portion of the same house, but where the daylight was of the same intensity, so far as the eye could judge. In twenty minutes the leaves of the two plants had opened somewhat, but *b* had opened more than *a*, which was within the field of the rays. The plants were then jarred a second time, and inter-

changed, *b* being placed under the rays. Ten minutes later *b* had opened slightly, while *a* had not opened at all; the sun by this time, 6 p. m. (June 12th), having passed below the top of a western building. While I intended at the time to repeat this experiment on the following day, the result shows quite conclusively, I think, that the difference manifested by these two plants in the rapidity of opening was due to individual peculiarities rather than to any influence of the Röntgen rays. For while it would at first appear that they exercised a slight inhibitory influence, the interchange of the plants shows that this was due to the more rapid response of the plant *b* to the influence of daylight.

In Schober's experiments the question as to whether the seedlings, or any parts of the plant, readily absorbed the Röntgen rays was not studied. From time to time, during the continuance of my own experiments, the field was explored with the fluoroscope to be certain that the rays were being evolved, and also an occasional photograph of the hand was made as a test of the strength of the rays. Good photographs were thus obtained with an exposure of from four to five minutes at a distance of 20 cm. to 25 cm. During the close of the first week's experiments the Crookes tube gradually deteriorated because of the high vacuum produced by prolonged use. This was first manifested in the resistance offered by the tube to the passage of the electric current. It was also manifested in some of the photographs taken at the time, the plates being affected unevenly, which indicated that the rays were given off more strongly in some directions than others. This bulb was discarded on June 12th, and a new one substituted on June 14th. Since it is well known that the Röntgen rays pass quite readily through wood the non-absorption of the rays by the plants might explain the absence of any marked influence upon them. Consequently, this subject received some attention, and attempts were made to obtain Röntgen photographs of some of the plants experimented upon, as well as of some other plant parts. The greater number of the exposures were made by placing both the sensitive plate and the object inside an ordinary card box, in which the plates are sold, a thin sheet of white paper being placed between the sensitive film and the object. A plate of a high sensitometer was used.

The first object used was an oak leaf (*Quercus rubra*). This was exposed, first for four minutes and a second time for three minutes. The leaf selected was a rather young and succulent one, thus being more difficult to photograph by transmitted light, but the older and firmer ones were too large for the size of plate used. The oak leaf was exposed for a longer time than would have been necessary if the method employed for a majority of the photographs, described above, had been followed in this case. Here, however, an ordinary plateholder was used, and a black rubber slide not only lay over the plate, but another was placed over the leaf, which was on the outside, to hold it in place. While in both of these cases an outline of the leaf and of the more prominent veins was obtained, better results were had when the exposure was made in an ordinary cardboard box. Here a fairly good outline of the leaf and of its venation was obtained. It is also to be observed that in the shorter exposure, which is needed for these delicate objects, a picture is also obtained of the structure of the box, the thin paper which is pasted on the outside, and overlaps the edges, showing quite plainly. Röntgen photographs of five seedlings which had for several days been under the influence of the rays were made. These were cotton, pea, nonpareil bean and soja bean, the cotton and one of the nonpareil

bean seedlings being grown entirely under the rays. Good outlines of the leaves and tracings of the principal veins were obtained, while the stems, roots and cotyledons of the pea and beans made strong pictures. The contrast between the general groundwork of the leaves and the surrounding space is quite strong, which shows that there was considerable absorption of the Röntgen rays even by the delicate seedlings experimented upon, and that the absence of any marked injury or other influence could not be due to non-absorption of the rays.

The other plant parts which were photographed by the Röntgen rays are the following: Leaves of two species of Begonia, in which quite strong pictures of the leaves and of the venation were obtained. The venation of B, rex, with rather prominent red veins coming out more strongly than B, nitida-alba, both were being taken on the same plate. The interior of various nuts, as almond, peanut, hickorynut, makes quite strong pictures. Good pictures were obtained of the endosperm (prothallium), of the fruit of cycas, also of the seeds of green peas and beans still within the pod. Flower buds of Fuschia show the pistill and stamens in position before opening and the delicate flowers of Begonia also absorb the rays sufficiently to be photographed, although the picture made was weak. Fruits of apricot and green fruit of the plum and pea absorb the rays so strongly that it is difficult to get a good contrast between the flesh and stone, while the ripe fruit of a black cherry (probably a variety of *Prunus avium*) gives better contrast. The placenta and young ovules of *Podophyllum peltatum* show rather indistinctly through the walls of the ovary. A knot in the pine board makes a distinct Röntgen photograph. The spadix and flowers of *Arisæma triphyllum* show distinctly through the spathe, and the vascular ducts of the stem are also photographed. In specimens of Peltandra, in which the spadix was entirely enclosed within the spathe the spadix and outlines of the staminate and pistillate flowers are quite distinctly shown in a Röntgen photograph, while the vascular ducts of the stem show quite strongly in the picture (see Plate I., Frontispiece).

It is thus seen that plant tissues absorb the Röntgen rays quite freely, and it is singular that there is not a more marked influence on growing parts, especially that there are no visible external injuries, even when the parts are exposed at close range a large part of the time during several days, since the general impression is that the rays, even with comparatively short exposures, are injurious to the human tissues.

The longer my experiments continued the more mysterious the whole subject seemed. On a dark night, when the electric-light rays were intercepted by a black screen, exploring the field with a fluoroscope there was an abundance of light, flashing and quivering with the variations in the electric transmission through the tube, penetrating, and yet capable of absorption to a considerable degree. That it should present no easily discernible influence for the time during which the work continued was cause for profound surprise.

G. F. ATKINSON.

CORNELL UNIVERSITY.

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*SOME CONSIDERATIONS UPON THE FUNCTIONS OF STOMATA.**

THE sporophytes of many Bryophyta and of all Pteridophyta and Spermatophyta have their epidermis pierced with minute openings known as stomata. These occur upon particular portions of the aërial structures, not being found upon roots, nor upon subaqueous stems and leaves. They always stand over masses of chlorophyll-bearing

* Read before Section K. of the British Association for the Advancement of Science, August 19, 1897.